A Global Vegetation Modeling System for NEWS

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Project hypothesis: Prognostic simulation of land-atmosphere interaction with respect to climate variability and change requires realistic representation of changing distributions of transpiring leaves in response to diurnal, seasonal, interannual, and longer-term changes in weather and climate.

Objectives & deliverables:

- Develop, parameterize, and evaluate a multi-scale vegetation modeling system (VMS) for simulating land-atmosphere exchanges of water, energy, and carbon that includes global prediction of leaf area index, through simulating vegetation geographic distribution and biogeochemical cycle.
- VMS will include options for simple climate-based prognostic phenology and for more dynamic phenology based on biogeochemical cycling, and the allocation of nutrients and the fate of organic matter.
- VMS will have improved representations of both vertical and horizontal redistribution of soil moisture and its interaction with root distribution in modulating physiological stress and the temporal dynamics of drought-deciduous ecosystems.
- VMS will be applied in both a prognostic climate model (Community Climate System Model, CCSM), and in a global operational diagnostic (data assimilation) model (Land Information System, LIS).

Technical approach and/or methods

- Based on Community Land Model (CLM3, Zeng et al, 2002; Dai et al, 2003; Bonan et al, 2003; Levis et al, 2004; Levis and Bonan, 2004), Biome-BGC (Running and Hunt, 1993; Thornton 1998; White et al, 2000), and the Simple Biosphere Model (SiB, Seller et al, 1996; Baker et al, 2003), adding prognostic phenology, ecosystem competition, subgrid-scale water redistribution, physiological stress, and canopy air space energy budget, to form CLM-DGVM-CN.

    - In the LIS, seasonal phenology is derived from monthly mean LAI obtained from MODIS imagery, which systematically overestimate growing season length, and underestimate interannual variability.

    - The most significant development in CLM since its incorporation into the LIS is the reorganization of the grid structure into collocated patches of plant functional types (PFTs), and the subsequent introduction of competitive dynamics transforming CLM into a DGVM.

    - Horizontal land surface heterogeneity is represented by a nested subgrid hierarchy in which each atmospheric grid cell is composed of fixed geographic landunits (e.g., lakes, cities, and vegetated), soil columns, and co-existing PFTs which compete for water and other resources. Biophysical processes are simulated for each subgrid units independently, and prognostic variables are maintained for each subgrid unit. Vertical heterogeneity is represented by a single vegetation layer, 10 layers for soil, and up to five layers for snow, depending on the snow depth.

Technical approach and/or methods (continued).

• The CLM3-DGVM simulates the distribution and structure of natural vegetation dynamically, using mechanistic parameterizations of large-scale vegetation processes. Each PFT (broadleaf deciduous trees, evergreen deciduous trees, C3 grass) is represented by an individual plant with the average biomass, crown area, height, and stem diameter of its population, by the number of individuals in the population, and by the fractional cover in the grid cell (Bonan et al 2003). With dynamic vegetation enabled, vegetation cover and LAI are predicted rather than obtained from prescribed surface datasets. Community composition and ecosystem structure are updated with an annual time step in response to establishment of new plants, resource competition, growth, mortality, and fire. An algorithm for leaf phenology (simular to Kucharik et al, 2000) updates LAI daily in response to air temperature and soil water.

• Leaves emergence and senescence summergreen trees are based on the accumulated growing-degree-days.

• Photosynthetic carbon assimilation, A, is calculated using enzyme kinetics (Farquhar et al, 1980) and is linked to stomatal conductance, gs, by the Ball-Berry-Collatz parameterization. The rate of photosynthesis depends on light, temperature, [CO2], and soil water.

• Possible development and testing of new phenological algorithms based on the biogeochemical benefit and loss approach, will entail new photosynthate allocate to leaves, stems, and roots based on PFTs and ecosystem condition (light, water, and nutrient).

• Peter Thornton CLM3-CN include algorithms for tracking carbon and nitrogen in soils, plants, and litter, and both N-limitation and C & N allocation within the ecosystem.

Technical approach and/or methods (continued).

- Include prognostic solution for canopy-air-space temperature, water vapor and CO2.

- New treatments of rooting distribution, transpiration, physiological stress, and hydrauic lifting in the multiple soil layers.

- The model will be parameterized using satellite products specifying fractional land coverage by plant functional types and the fraction of photosynthetically active radiation absorbed by plant canopies (FPAR).

- CLM-DGVM-CN PFTs will be initialized from the MODIS continuous vegetation product.

- Obtain 1-km meteorological driver data from LIS, and downscaling from large scale global reanalysis products using MICROMET.

- Model evaluation at multiple spatial scales will be performed using local measurements of micrometeorological fluxes and storage of water and carbon, stream discharge from instrumented catchments, and regional information about snow cover and water storage.

Data set needs (vegetation-related datasets available both at site and spatially distributed data, and cover as many diversified climate-ecosystem zones as possible):

MODIS NDVI-derived products for model initialization and parameterization.

VMS evaluation will first focus on process scales and aggregating to increasingly large area.

1. Testing the predictions of vegetation phenology against local observations:
   - IPG: observed phenology in phenological gardens (20 sites, 47 year long dataset, Europe only, http://www.agrar.huberlin.de/pflanzenbau/agrarmet/ipg_2.html)

2. Understanding the sensitivity of modeled land surface heat, water, and carbon fluxes to prognostic vegetation phenology at local scales:
   - FLUXNET: global 200 flux towers, 1995-present, eddy covariance water, energy, momentum, and carbon fluxes, soil temperature, and moisture profiles, micrometeorological observations (Baldocchi et al, 2001)
   - Evaluate physiological stress representation, seasonal drought in Oregon and Oklahoma; interanual changes in dry-season duration and severity at Tapajos sites

3. Evaluation of biogeochemical cycling against local measurements of biogeochemical fluxes and pool sizes in well-studied ecosystems:

   LTER: ground observed vegetation states (26 sites, 20 year long dataset, USA only, http://www.lternet.edu/)

4. Comparison of aggregated spatially-explicit predictions of soil moisture and runoff against soil moisture data and stream discharge measured from gauged catchments:
   - Oklahoma mesonet (Illston et al., 2003)
   - SMEX campaigns in Oklahoma, Alabama, Georgia and Brazil. More detailed information regarding the SMEX03, including AMSR images, photos, and experiment plans, can be found at: http://hydrolab.arsusda.gov/smex03/
   - GRDC: Global river runoff time-series of catchments and sub-catchments, worldwide availability and long-term coverage. (http://grdc.bafg.de)

5. Comparison of regionally-aggregated prediction of snowpack distribution and total water storage against global satellite observations
   - snow depth and cover data NASA Cold Land Processes Experiment (CLPX) (http://www.nohrsc.nws.gov/~cline/), and NOAA National Operational Hydrologic Remote Sensing Center (NOHRSC) (http://www.nohrsc.nws.gov/), MODIS (NASA's TERRA and AQUA satellites) snow cover (1km, global)
   - GRACE (NASA's Gravity Recovery And Climate Experiment): monitoring capability of the large-scale water cycle, especially of changes in the terrestrial water storage, including deep groundwater and snow depth (global coverage, 2002-present)

Project outputs (project results that may be made available to the NEWS team for subsequent use – include potential size/resource requirements):

- Multi-scale VMS with prognostic phenology predicting both vegetation biogeographic distribution and biogeochemistry cycle.
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Potential collaborations (with NSIT, other NEWS projects, etc.) :

- NASA Land Information System (LIS), Peters-Lidard
- Others on land-atmosphere interactions
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Important outside linkages/resources (outside the NEWS team) :

- Thornton from NCAR, who serves on CCSM Land Model working group, is improving CLM3 biogeochemistry by implementing the terrestrial carbon and nitrogen cycles in it. He showed how his new parameterization of sunlit and shaded portions of the canopy improves the simulated global photosynthesis.
- CENTURY nutrient cycle and SOM, Parton and Ojima, NREL of CSU
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Expected contribution to the NEWS objective:

- Our phenology and vegetation dynamics research will use multiyear timeseries of optical imagery from space and multiple NASA data products to address a persistent bias in the timing of seasonal canopy development (LAI), and will combine ecophysiology and carbon and nitrogen biogeochemistry with soil and snow hydrology, spatial scaling, and data assimilation.

- The new modeling system will link exchanges of water and energy with those of carbon and nitrogen in a biophysically and biogeochemically realistic way, and will allow a new set of observational constraints (e.g., biomass surveys, soil carbon, atmospheric trace gas inversion of CO_2) to be brought on hydrologic problems.

Issues, needs, and concerns (to be discussed in breakouts, teaming discussions, etc.):

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